



Observatoire
Astronomique
de
Strasbourg

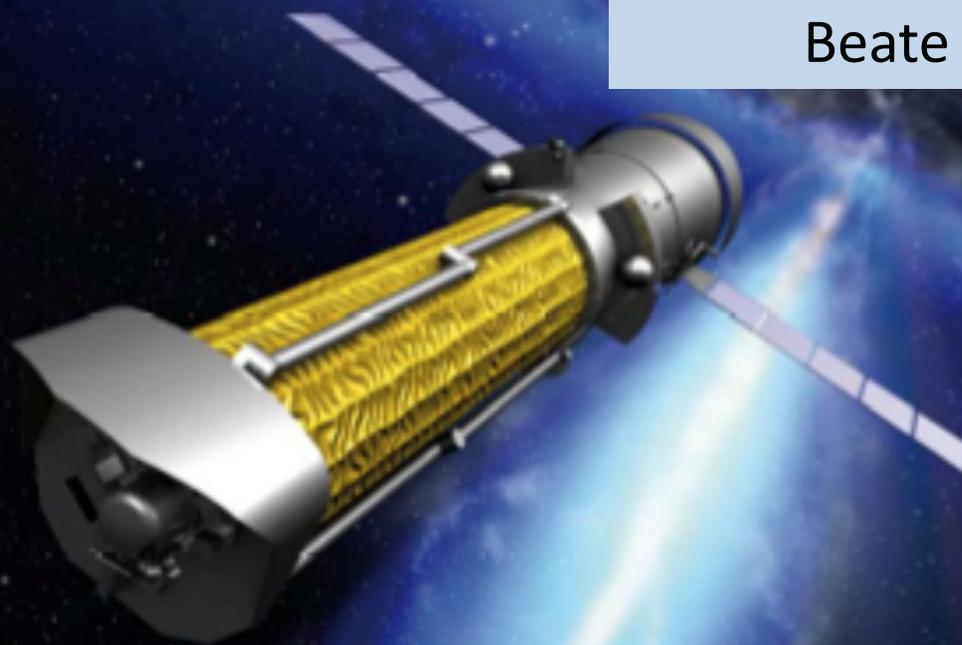


IXO

+

Stars

Beate Stelzer (OA Palermo)



Stellar X-ray sources

Wolf-Rayet stars

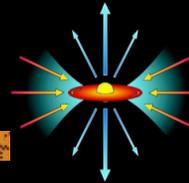
OB-stars

Winds,
magn.fields



A(p)-stars

protostars
(Class 0; Class I)



Pre-main sequence stars
(= T Tauri stars)

Accretion,
Jets, coronae

Solar-type stars

coronae



Very low-mass stars
+brown dwarfs

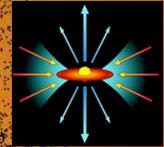
Coronae?



Stellar science with IXO

Topics of this talk:

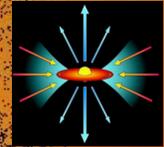
- Origin of the X-ray emission from brown dwarfs
- [Accretion onto young stars (+ brown dwarfs)]
Talk Audard; Poster Argiroffi
- Nature of the Fe $K\alpha$ emission in pre-main sequence stars
- Massive stars (OB-stars, WR-stars)



Stellar science with IXO

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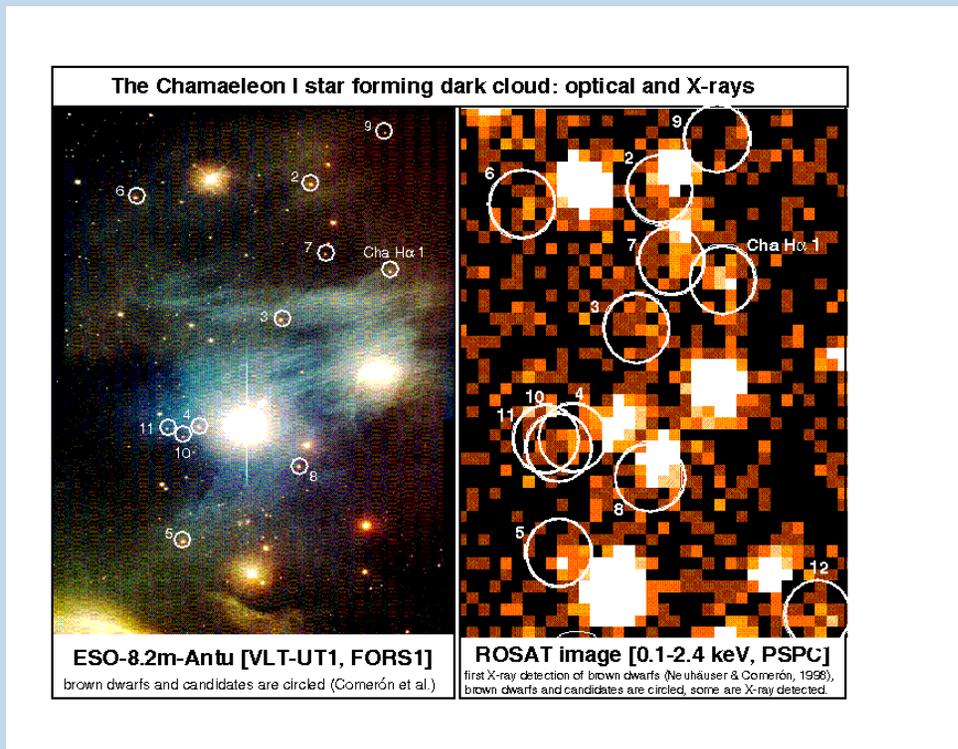
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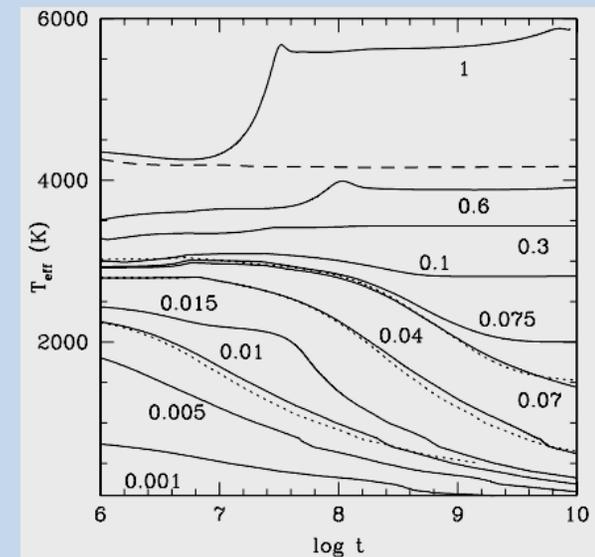
X-rays from brown dwarfs

1st X-ray detection of a brown dwarf with ROSAT in Cha I (Neuhäuser & Comerón 1998, Sci 282):

- young BDs are brighter (in X-rays) than old BDs [if $L_x/L_{bol} \sim \text{const.}$]
- star forming regions are crowded \rightarrow need spatial resolution



BD cooling curves (Chabrier & Baraffe 2000)



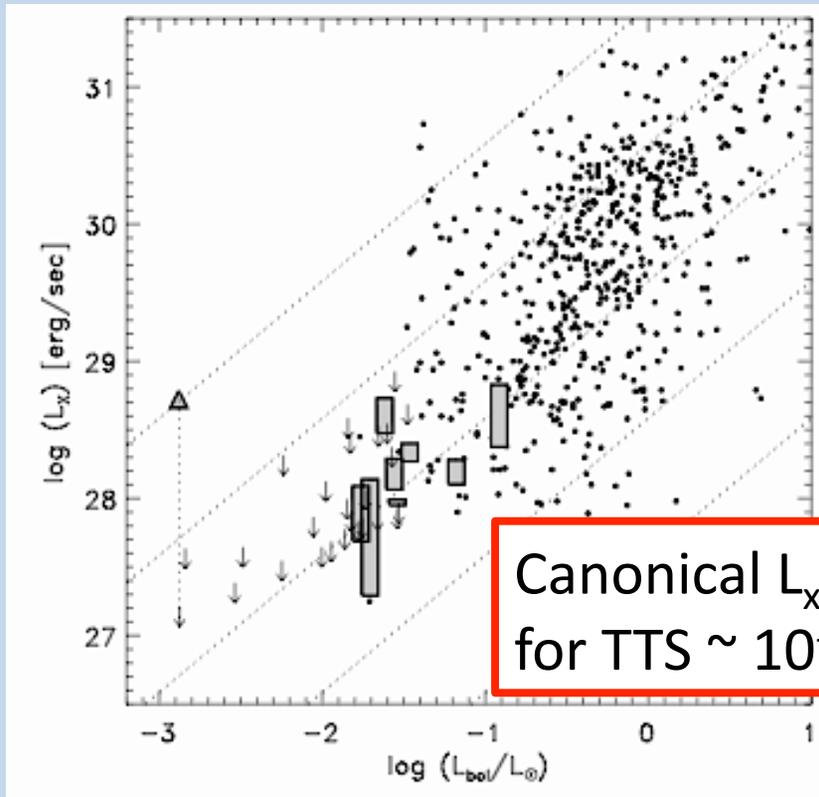
- Are young BDs substellar analogs to T Tauri stars?
- How does X-ray emission (dynamo) of BDs evolve with age?

Watch out: Source confusion !

Brown dwarfs:

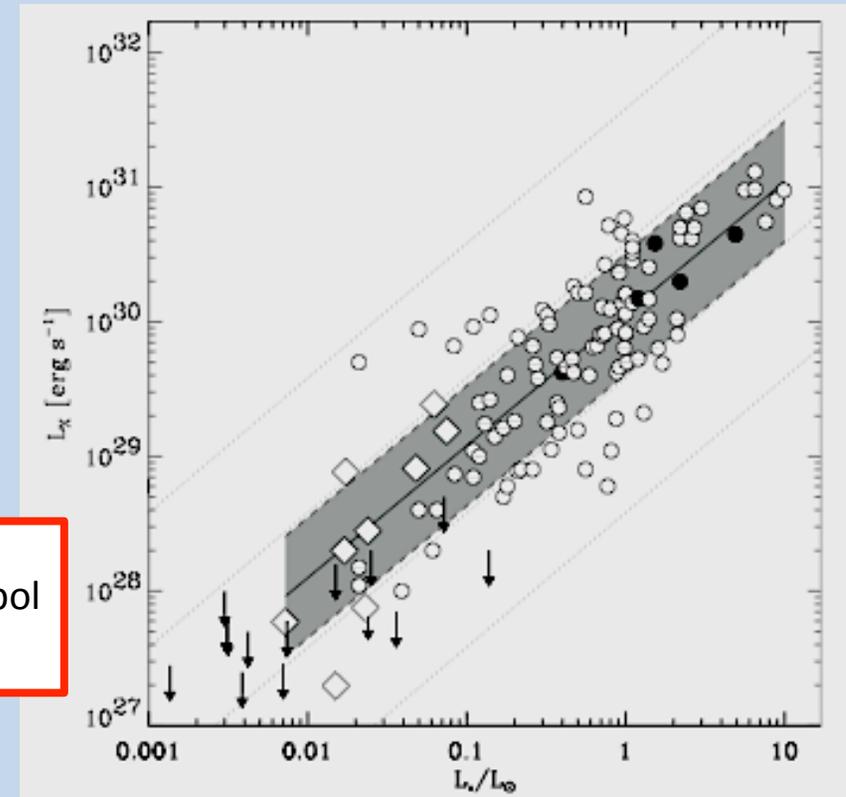
Dynamo in the substellar regime compared to TTS?

COUP (ONC) -- 1 field for 850ks Chandra



Preibisch et al. (2005)

XEST (TMC) -- 19 fields for 30 ks XMM



Grosso et al. (2007)

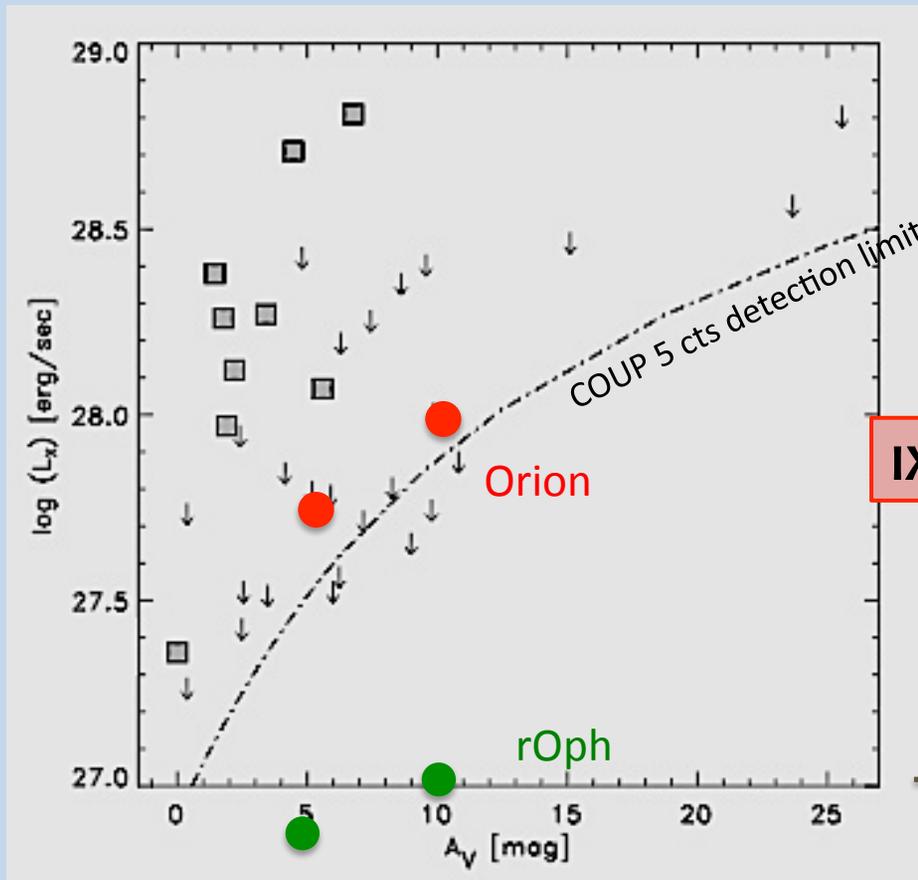
Is L_x/L_{bol} of BDs in star forming regions comparable to higher-mass stars or lower?

Currently too few BDs are detected in X-rays.

Detecting brown dwarfs with IXO/WFI

COUP: 850ks Chandra in Orion

→ Only weakly absorbed BDs detected



Preibisch et al. (2005)

Assume a strongly absorbed BD in ONC:

1) Intrinsic $L_x = 10^{28.0}$ erg/s with $A_V = 10$ mag

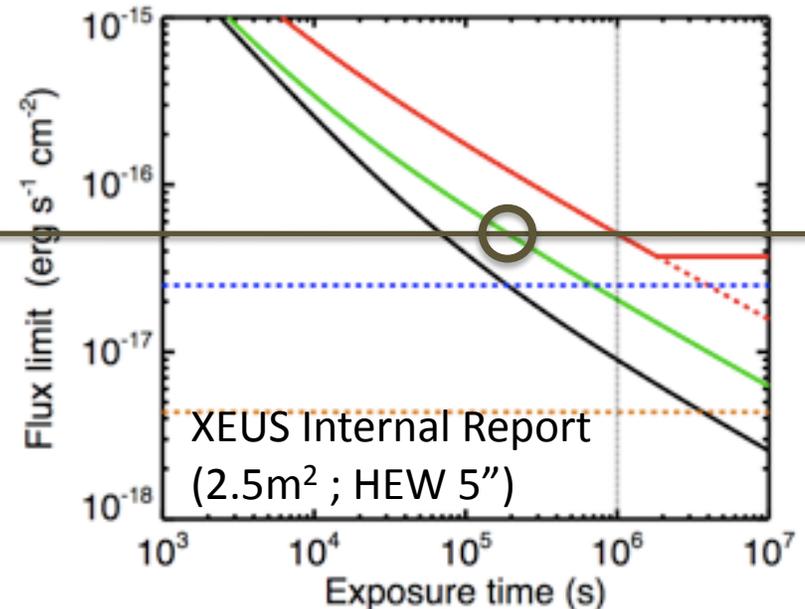
2) Intrinsic $L_x = 10^{27.8}$ erg/s with $A_V = 5$ mag

@ 450 pc

$(f_x)_{\text{abs}} \sim 5 \cdot 10^{-17}$ erg/cm²/s

@ 0.5-2 keV for $kT = 1$ keV

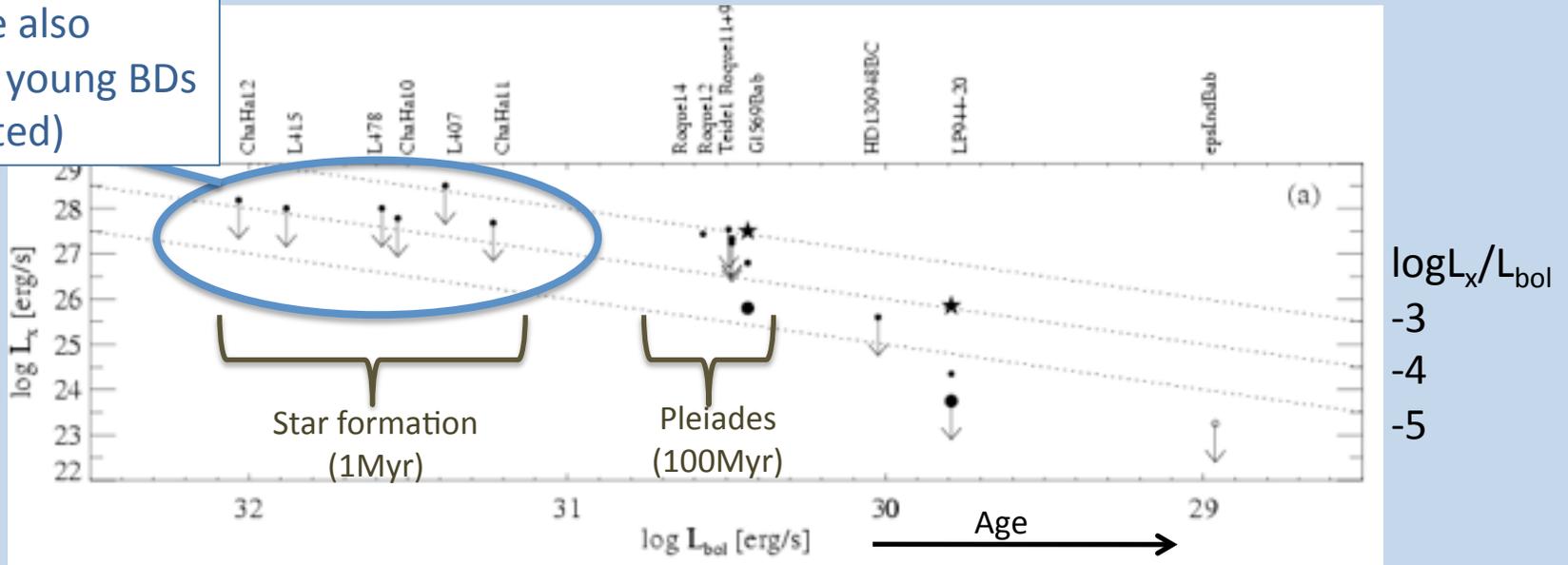
IXO/WFI: detects these objects in ~200 ks



Brown dwarfs:

Evolution of the dynamo in the substellar regime ?

There are also
detected young BDs
(not plotted)



Stelzer et al. (2006)

- L_x / L_{bol} decreases with age and/or T_{eff}
Interpretation: increasingly neutral atmosphere \rightarrow poor coupling matter/magn.field
- Only 1 L dwarf detected in X-rays so far (Audard et al 2007)
- Evolved BDs may have $L_x \sim 10^{25}$ erg/s

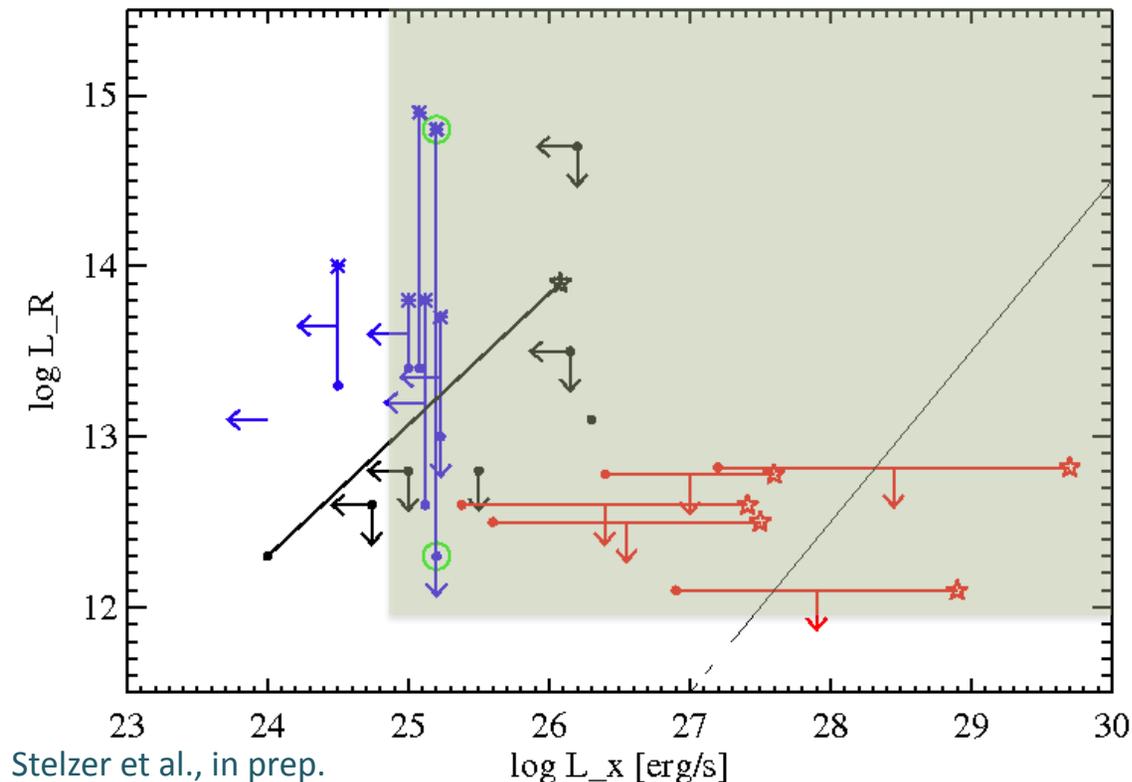
Radio – X-ray relation for ultracool dwarfs ?

Benz-Guedel relation
is violated (e.g. Berger et al. 2002)

- UCDs with bright radio emission show radio bursts
→ Electron Cyclotron Maser
(Hallinan et al. 2006; 2008)
but no or very weak X-rays

- UCDs without detectable radio emission but with X-ray flares

- LP944-20 has both radio spikes and X-ray flares

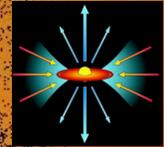


IXO/WFI: detects objects with $\log L_x \sim 25$ erg/s
in ~ 20 ksec out to ~ 20 pc
incl. ~ 100 L dwarfs + many late-M dwarfs
(E-VLA reaches $\log L_R \sim 12$ erg/s/Hz in same time)

Stellar science with IXO

Topics of this talk:

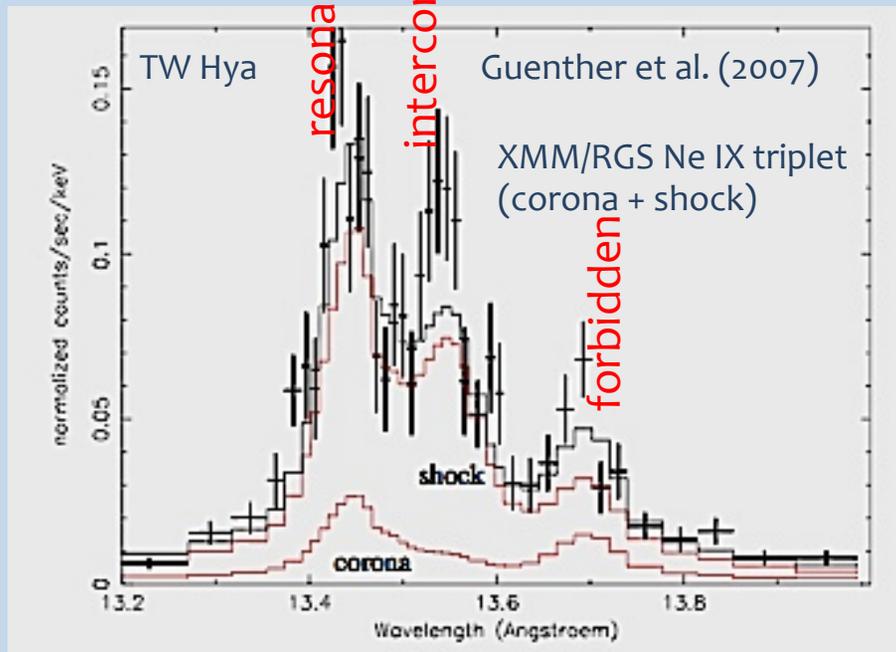
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High-resolution X-ray spectroscopy: Densities from He-like triplets

- Diagnostic for accretion shock: high-density ($\sim 10^{12} \text{ cm}^{-3}$)
(vs. low-density corona $\sim 10^{10} \text{ cm}^{-3}$)

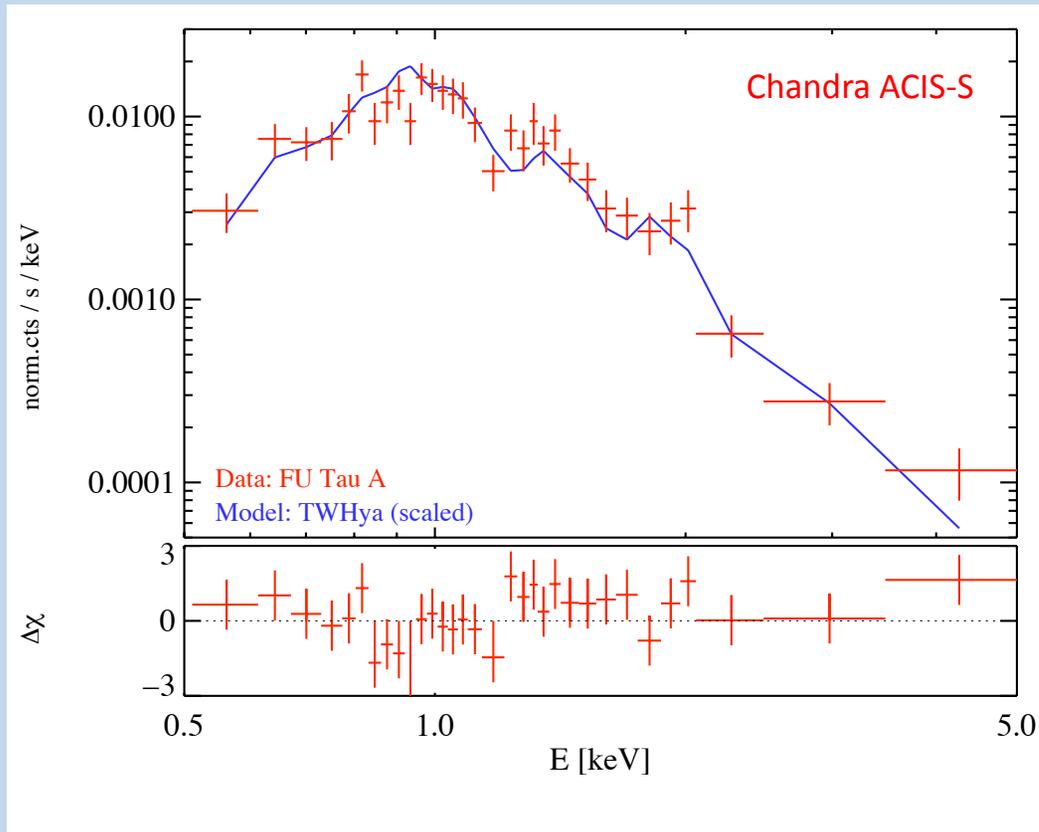
→ line diagnostics, He-like triplets: **low f/i flux ratio indicates high n_e**



Only 7 cTTS bright enough
for XMM/Chandra gratings.

See
Talk by M.Audard
+
Poster by C.Argiroffi

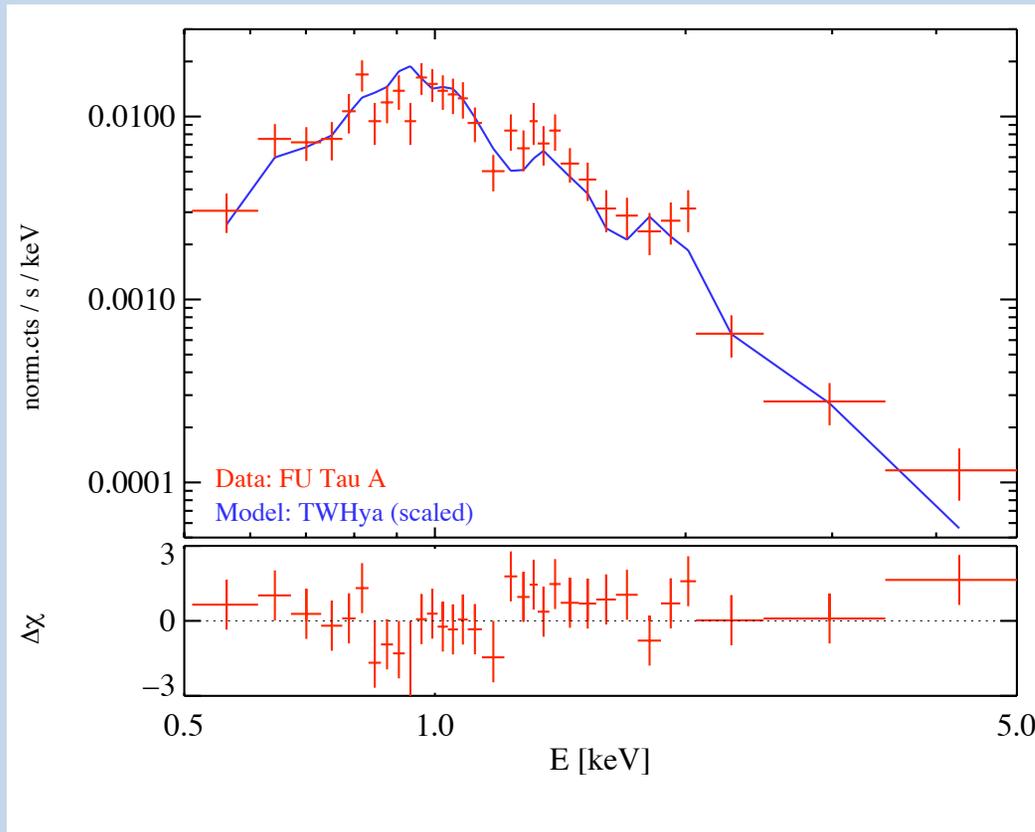
Brown dwarfs: X-rays from accretion shocks?



Highest quality X-ray data
for a BD so far:
~ 600 cts for FUTauA

Stelzer et al. 2010

Brown dwarfs: X-rays from accretion shocks?



Stelzer et al. 2010

Highest quality X-ray data
for a BD so far:

~ 600 cts for FU Tau A

→ Untypically low
temperature (0.24 keV);
as in the prototype
accreting TTS TW Hya !

X-rays from accretion
diagnosed by

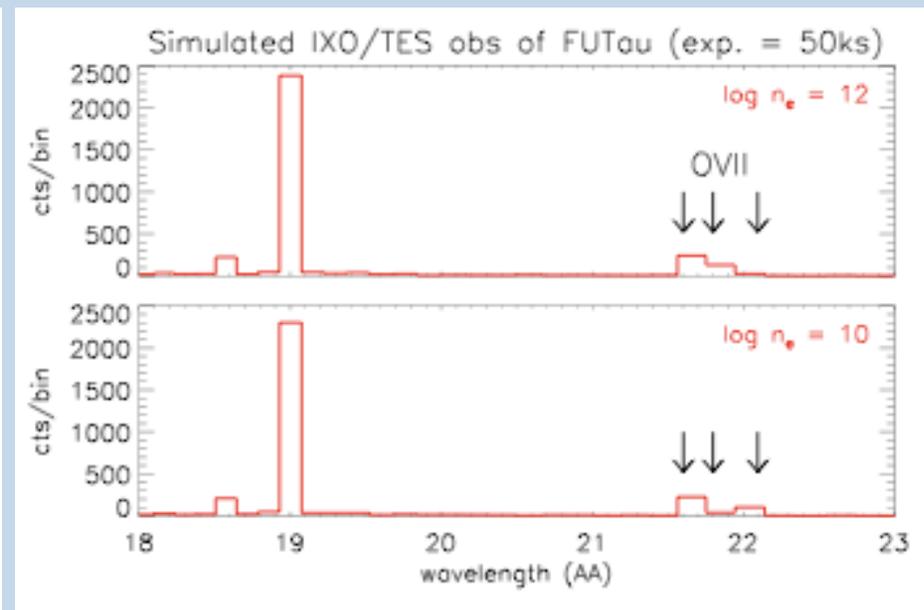
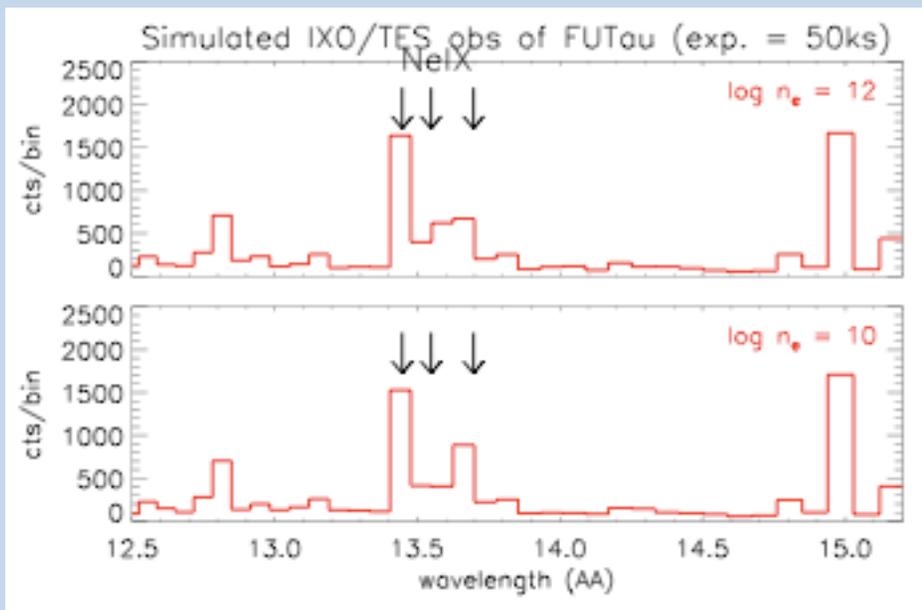
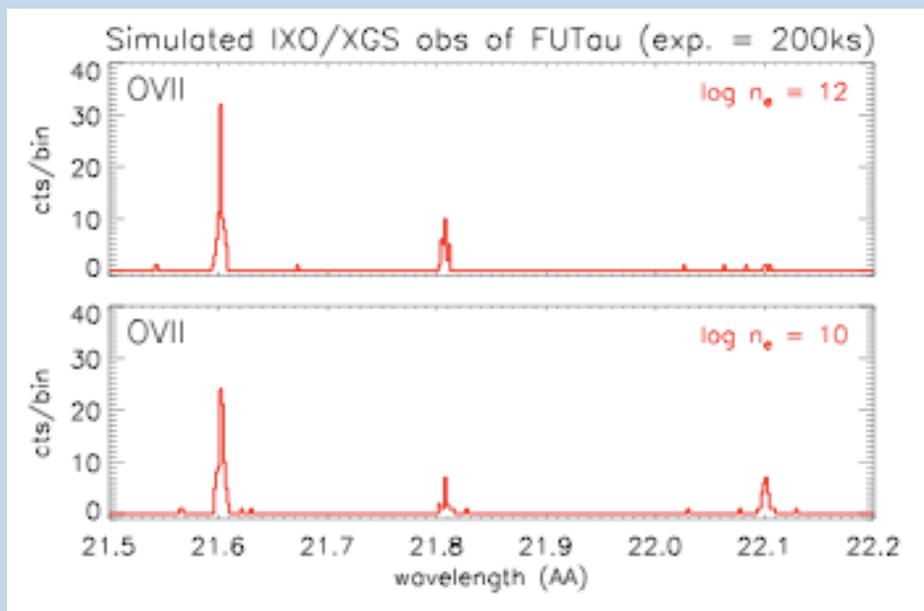
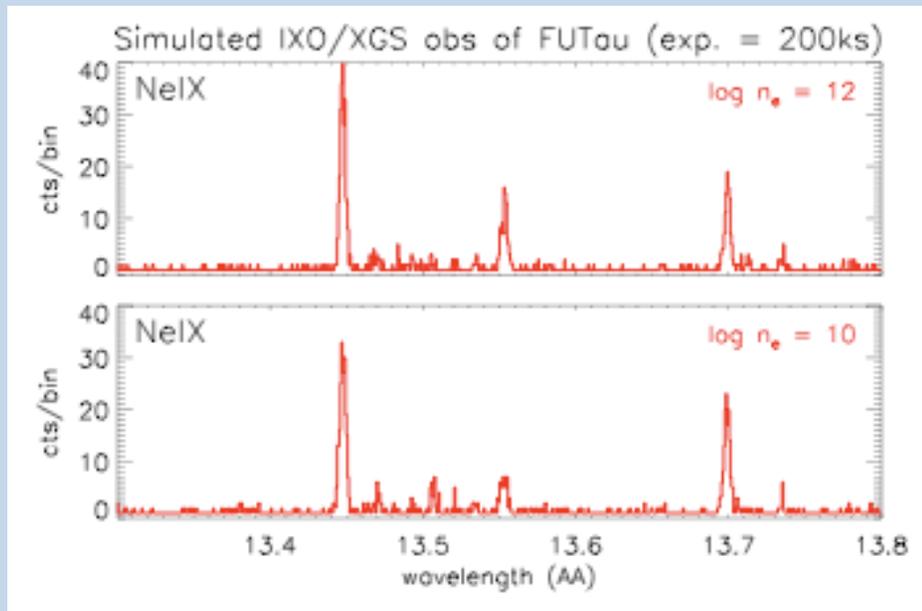
1) Soft spectrum

$$T_{\text{psh}} = \frac{3}{16} \frac{\mu m_p}{k_B} v_0^2$$

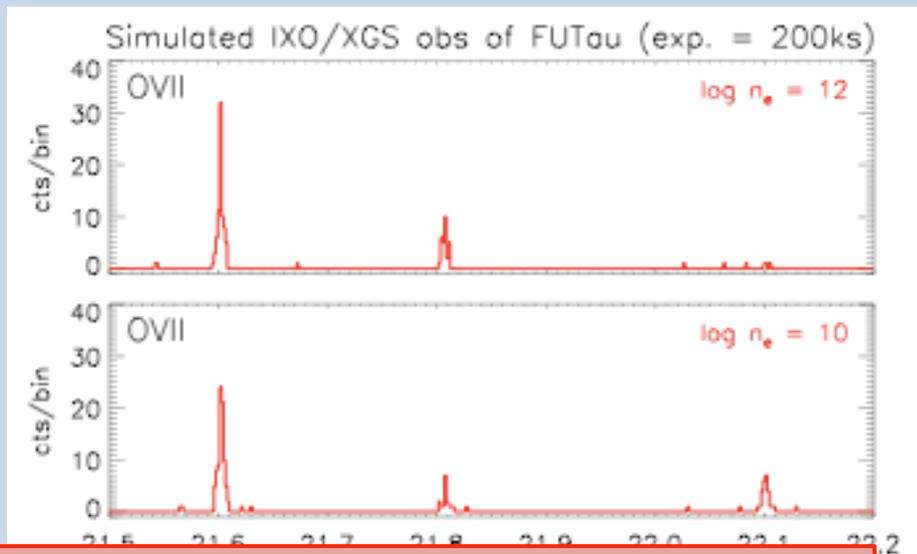
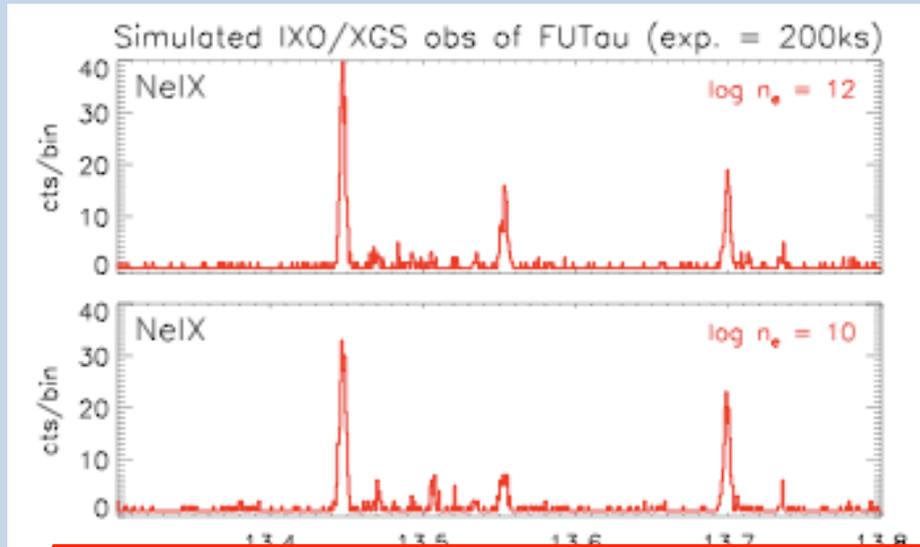
2) High density

IXO/WFI can sample statistical numbers of low-resolution spectra for BDs
to determine X-ray temperature.

High-resolution spectra of brown dwarfs with IXO

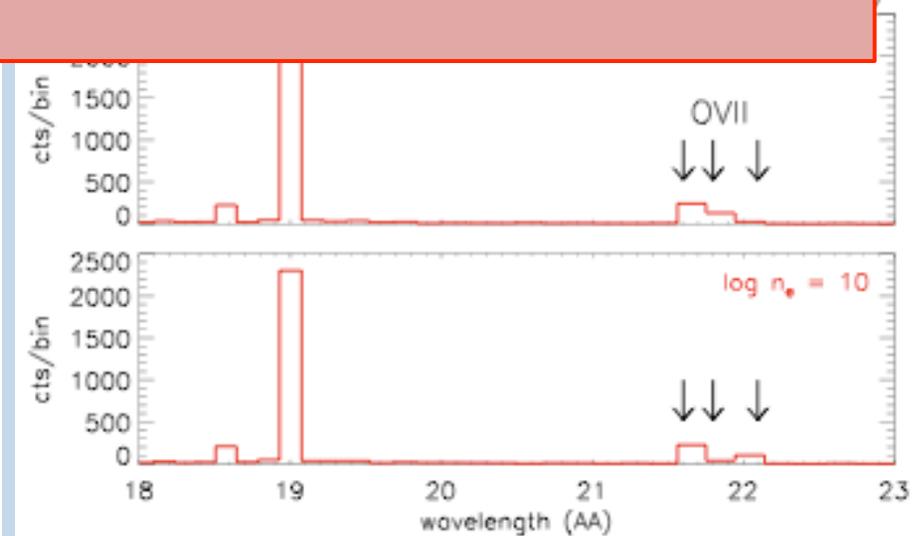
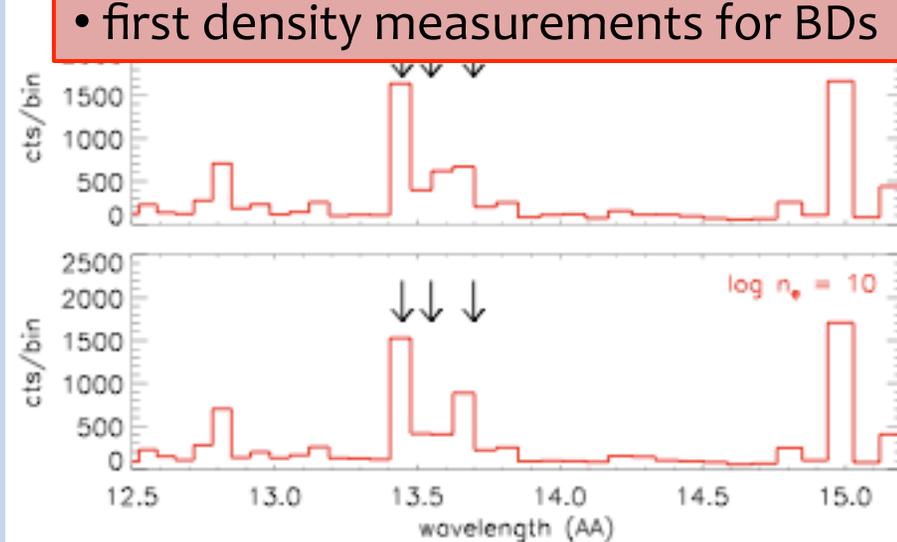


High-resolution spectra of brown dwarfs with IXO



IXO/XGS(+XMS) potential:

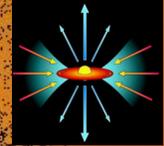
- first density measurements for BDs



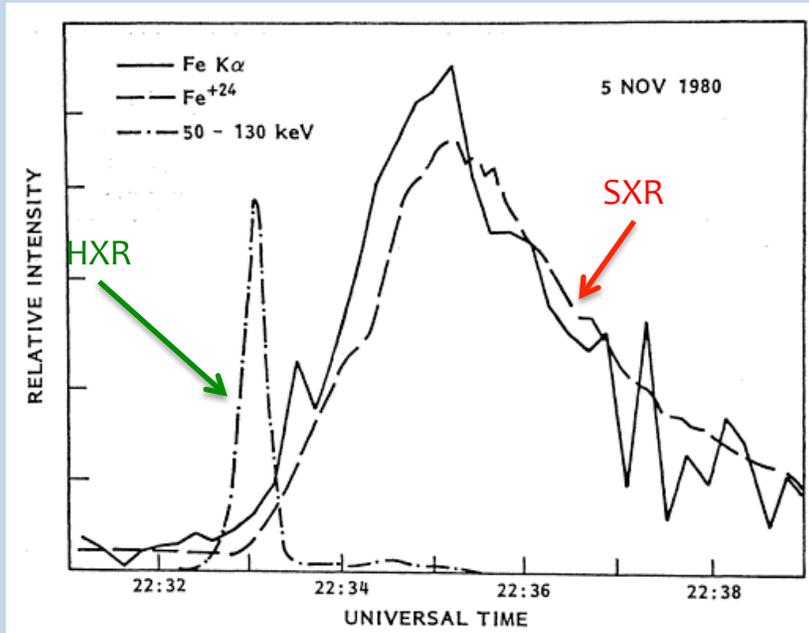
Stellar science with IXO

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Fe K α emission from the Sun

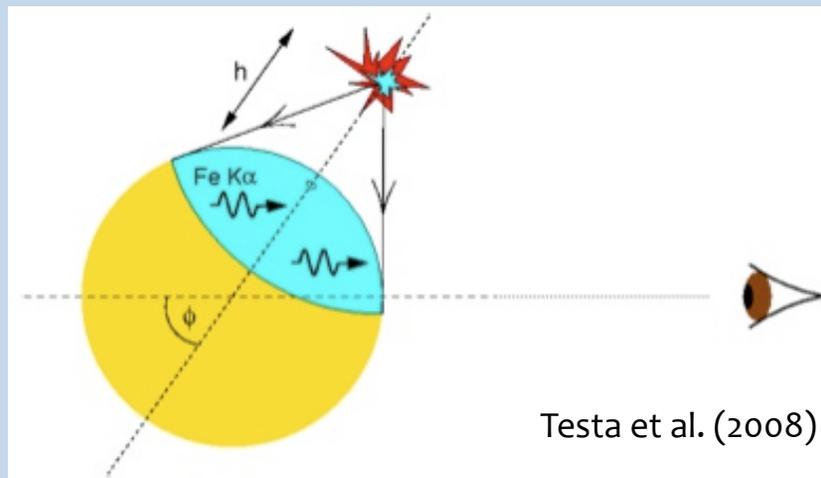


Culhane et al. (1981)

Sun:

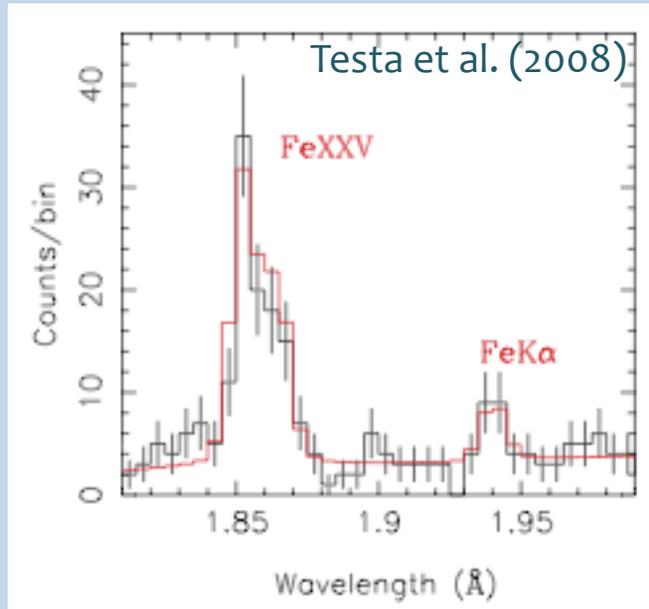
6.4 keV K α line
during gradual phase of flare
(similar to soft thermal X-rays;
unlike hard non-thermal X-rays)

→ fluorescence of photosphere
illuminated by X-rays



Testa et al. (2008)

Fe K α emission from normal stars: Fluorescence \rightarrow flare location



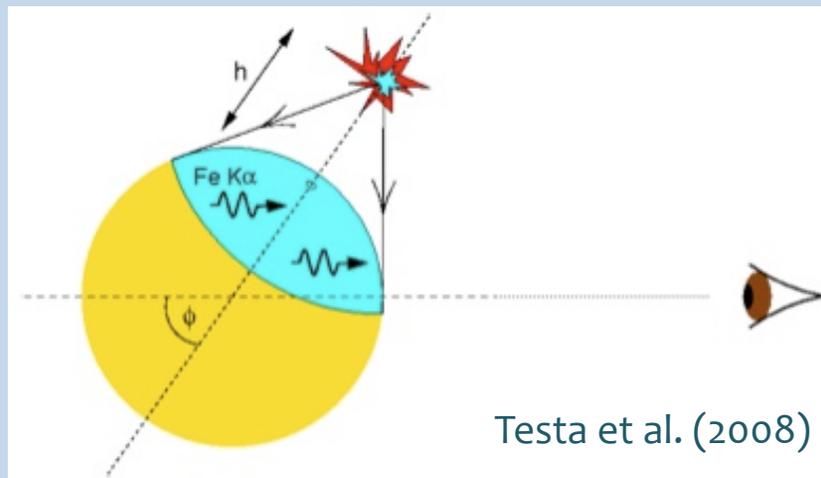
HR9024 (G giant)

6.4 keV K α line

during initial phase of flare

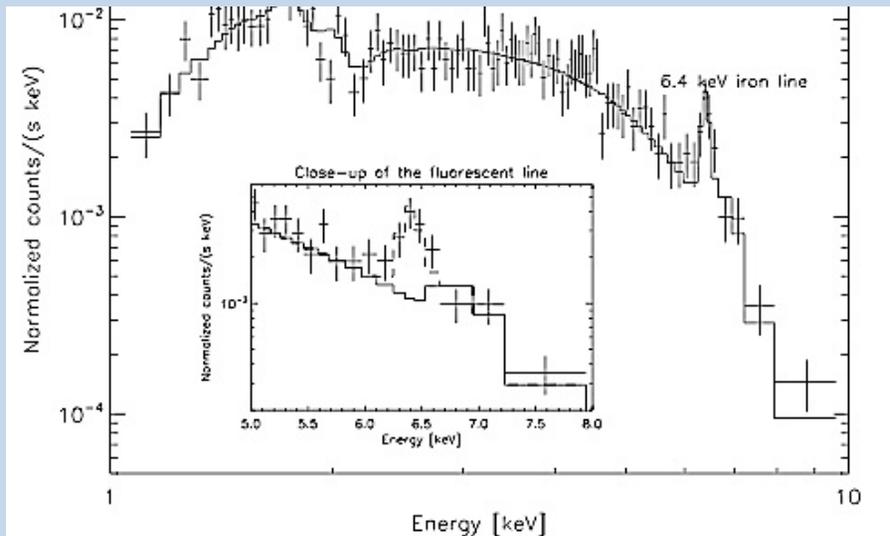
photospheric fluorescence model
constrains flare height: $\sim 0.1 R_*$

see also Osten et al. (2007)



In pre-MS stars
Fe K α emission comes from disk
(e.g. Tsujimoto et al. 2005)

Fe K α emission from pre-MS stars: fluorescence or e⁻ impact ionization ?

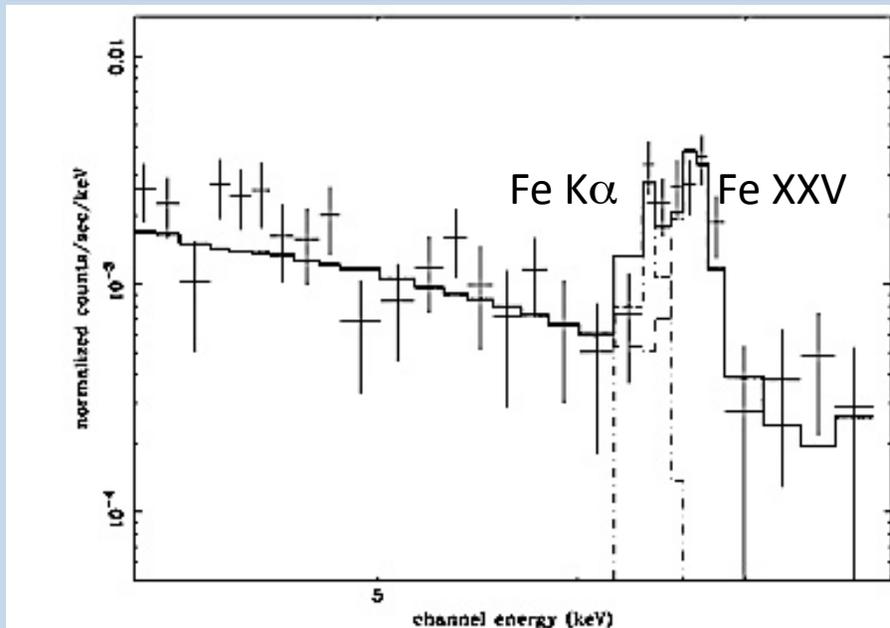


V1486Ori (COUP #331)
– Czesla & Schmitt (2007)

No 6.7keV line (very hot plasma; > 10 keV)

Very strong 6.4keV line ($W \sim 1400$ eV)
for short time during flare rise

fluorescence calculations underpredict
observed K α flux

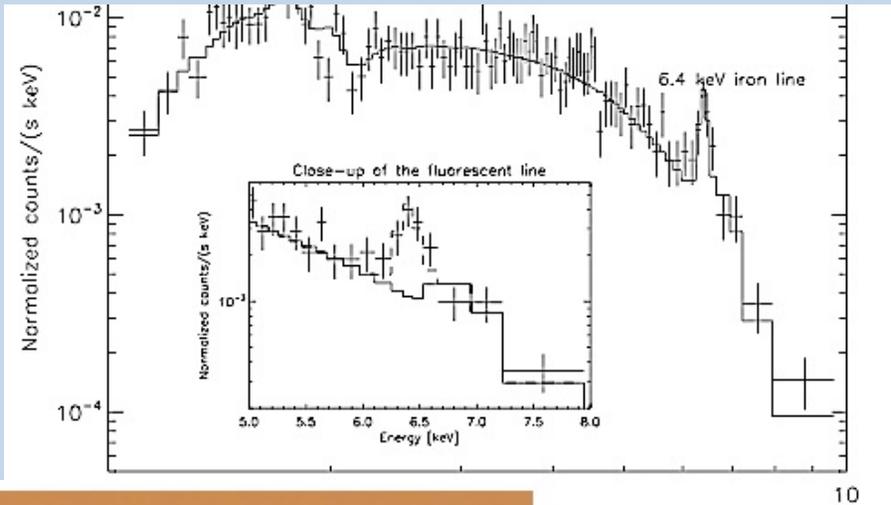


Elias 29 (DROXO)
-- Giardino et al. (2007):

6.4keV line
in quiescent phase after a flare

sustained ionization mechanism
independent of X-rays;
coll. ionization by non-thermal
electrons in star-disk loops

Fe K α emission from pre-MS stars: fluorescence or e⁻ impact ionization ?



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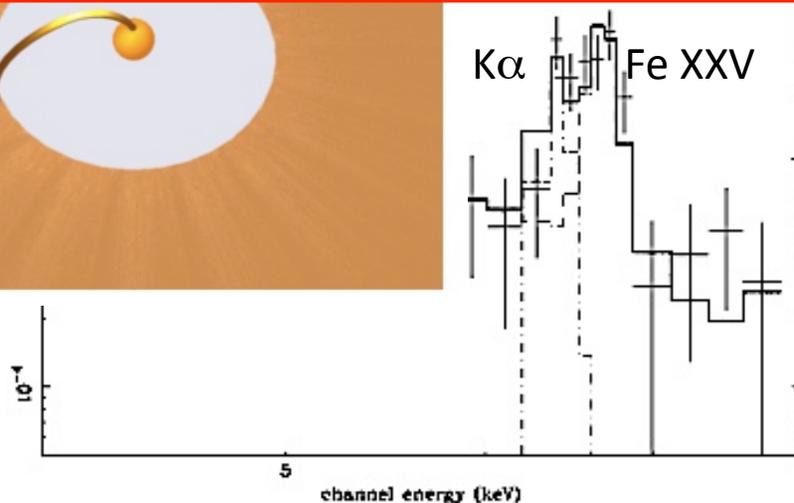
Very strong 6.4keV line ($W \sim 1400$ eV)
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fluorescence calculations underpredict

IXO: Reverberation mapping reveals geometry of system
time-delays continuum vs. line emission $r \sim 10$ AU $\rightarrow dt \sim 5$ ksec



K α Fe XXV

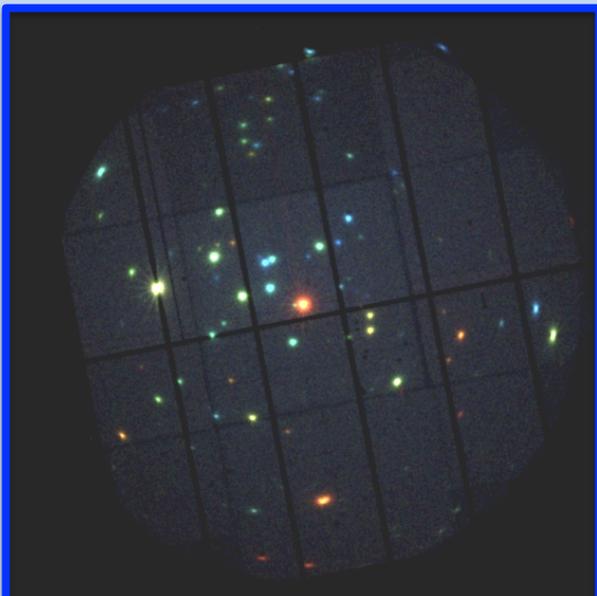


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Time-resolved studies of Fe K α emission



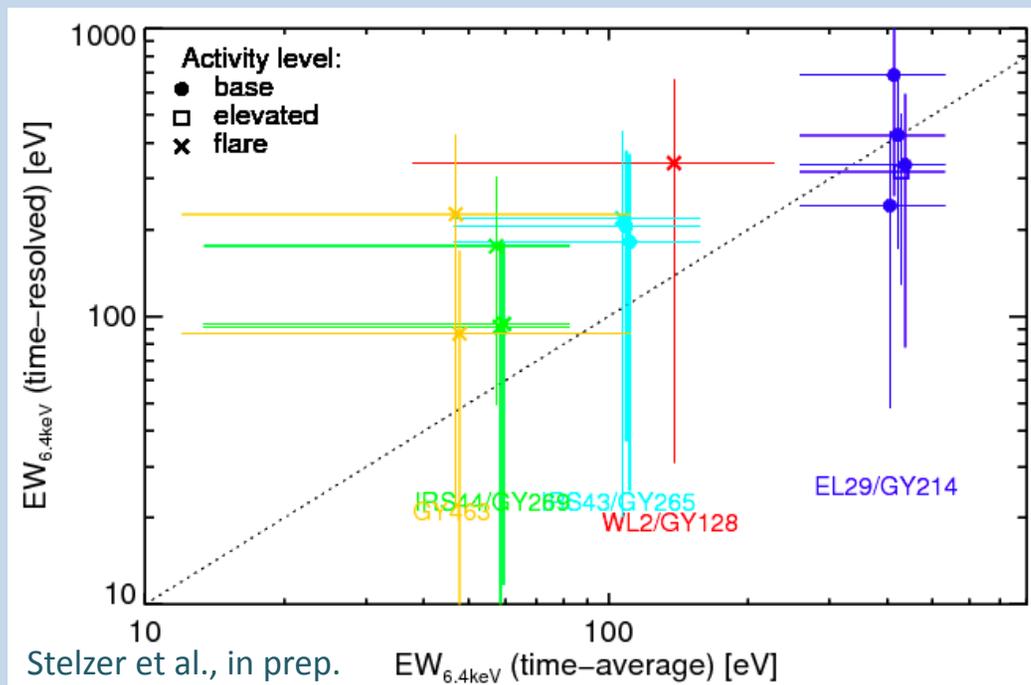
500 ks XMM-Newton
in ρ Oph Core F

PI Sciortino

3 paper published,
others in prep.

DROXO:

Fe K α detected in several time-intervals for 5 stars

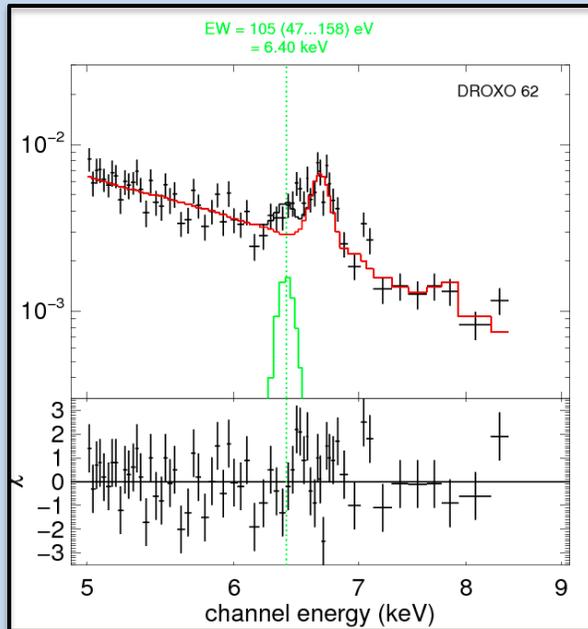


Result:

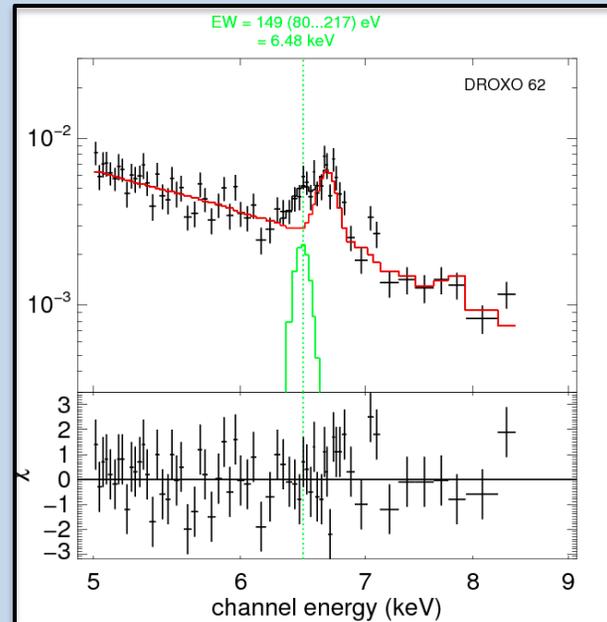
Time-resolved spectroscopy yields higher equivalent widths than time-averaged spectroscopy.

Time-resolved studies of Fe K α emission

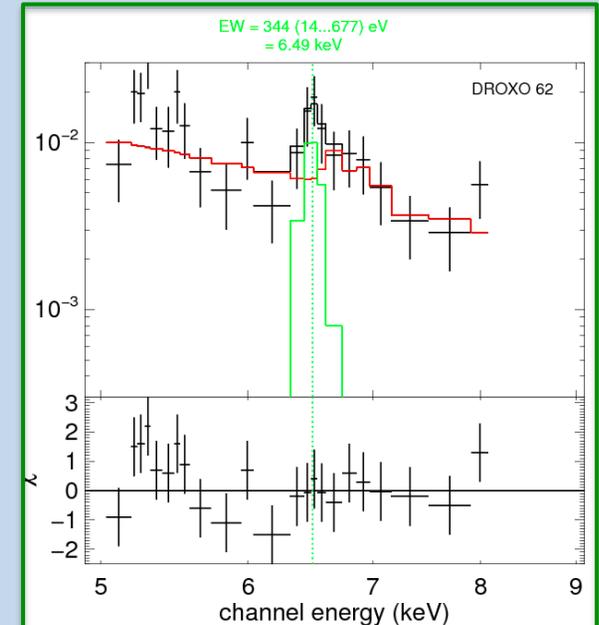
The DROXO source IRS 43 (Class I):
Stelzer et al., in prep.



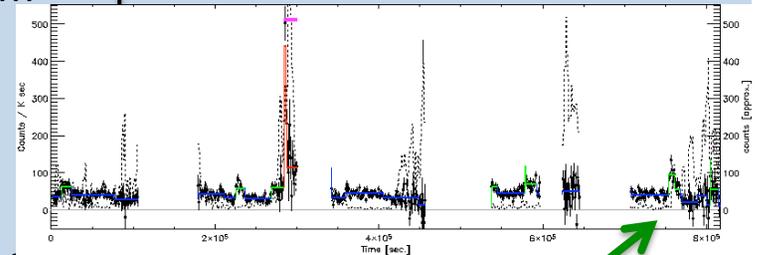
Time-averaged spectrum
with line-energy fixed
at 6.4 keV
→ Residuals between
6.4 and 6.7 keV



Time-averaged spectrum
with free line energy
→ 6.48 keV
→ Ionized iron
(Fe XIX...Fe XXIII);
No disk fluorescence?

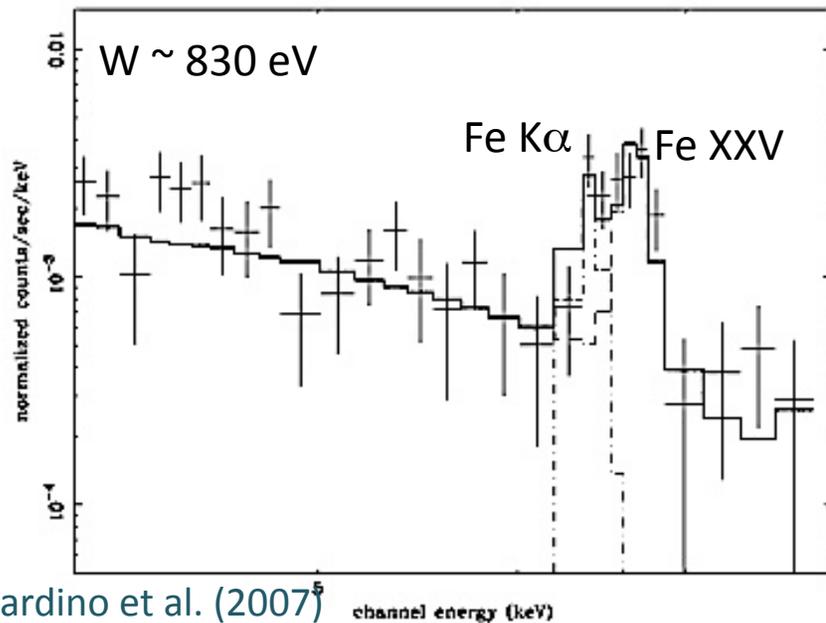


Time-resolved analysis
→ Shift of line energy
during small flare

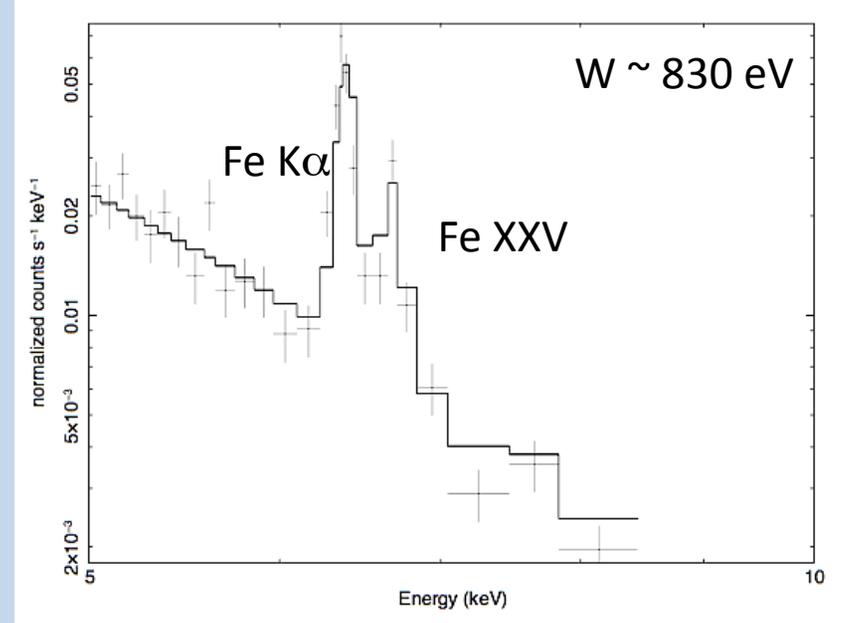


Fe $K\alpha$ emission with IXO/WFI

85 ksec XMM/pn



25 ksec IXO/WFI



IXO/WFI + XMS:

Time-resolved Fe $K\alpha$ spectroscopy:

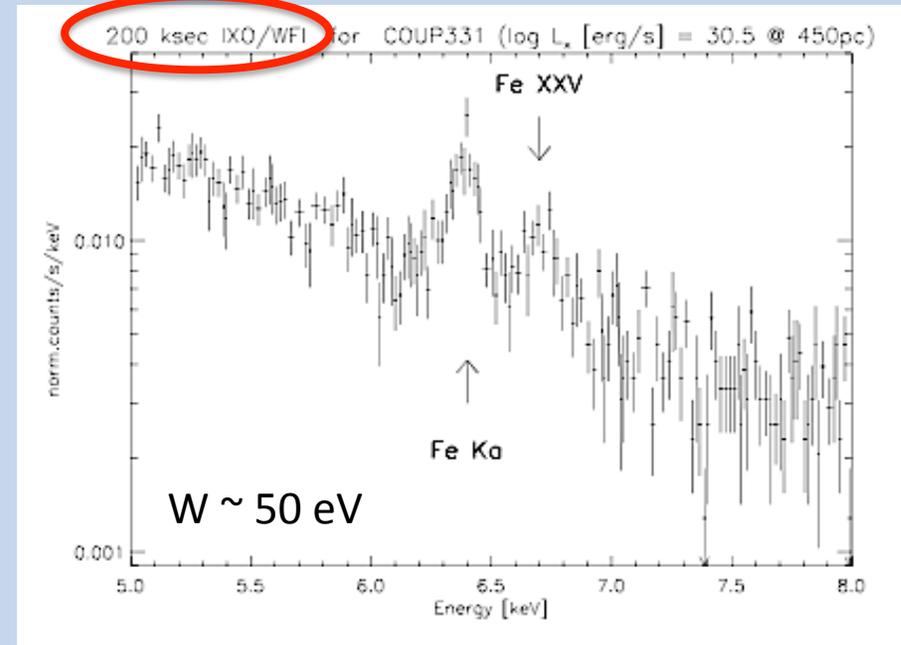
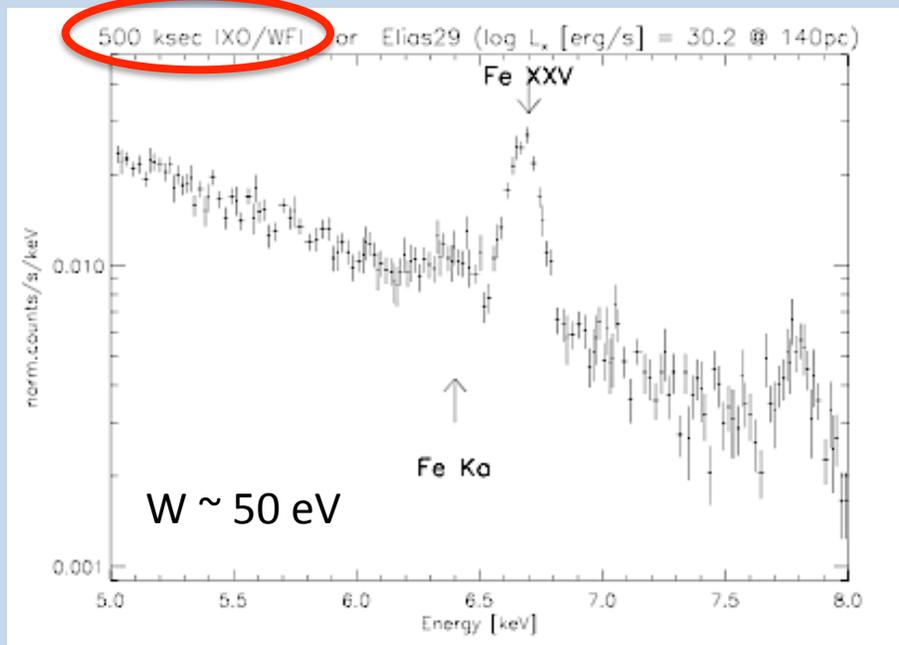
- detecting time-delay between flare and appearance of Fe $K\alpha$ line from disk
- measuring line shifts + relation to activity state

IXO/HXI:

- good constraint on high-energy (>7.1 keV) continuum
- correlation of Fe $K\alpha$ with HXR or SXR ? \rightarrow electron impact or photo-ionization

large FOV \rightarrow several stars in 1 field (dependence of Fe $K\alpha$ on evol. State)

Fe $K\alpha$ emission with IXO/WFI



Detection of weak Fe $K\alpha$ depends on spectral shape of continuum!

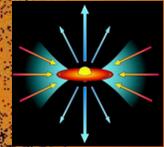
IXO/WFI + XMS:

- detect photospheric Fe $K\alpha$ fluorescence ($W_{H\alpha} \sim 50$ eV in few 100 ksec):
modeling photospheric fluorescence efficiency

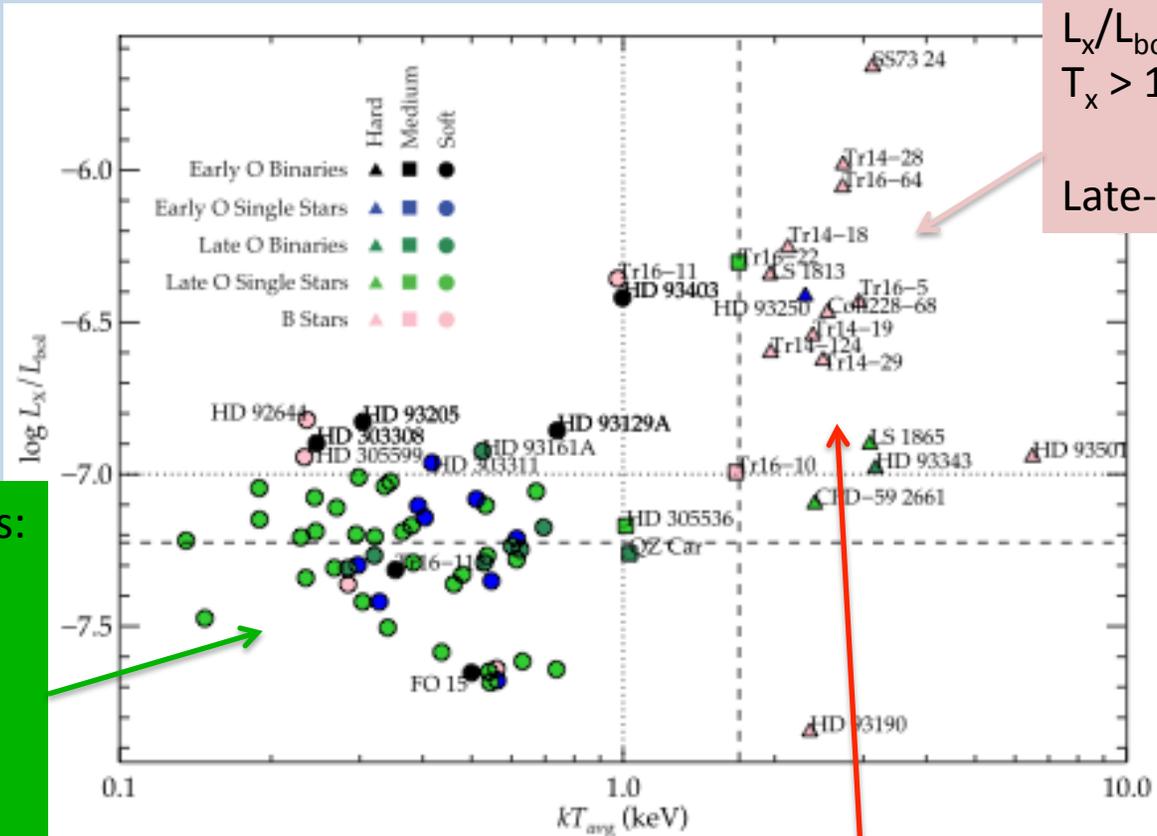
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X-ray emission mechanisms for hot stars



B stars:
 $L_x/L_{bol} > 10^{-7}$
 $T_x > 1$ keV

Late-type companions

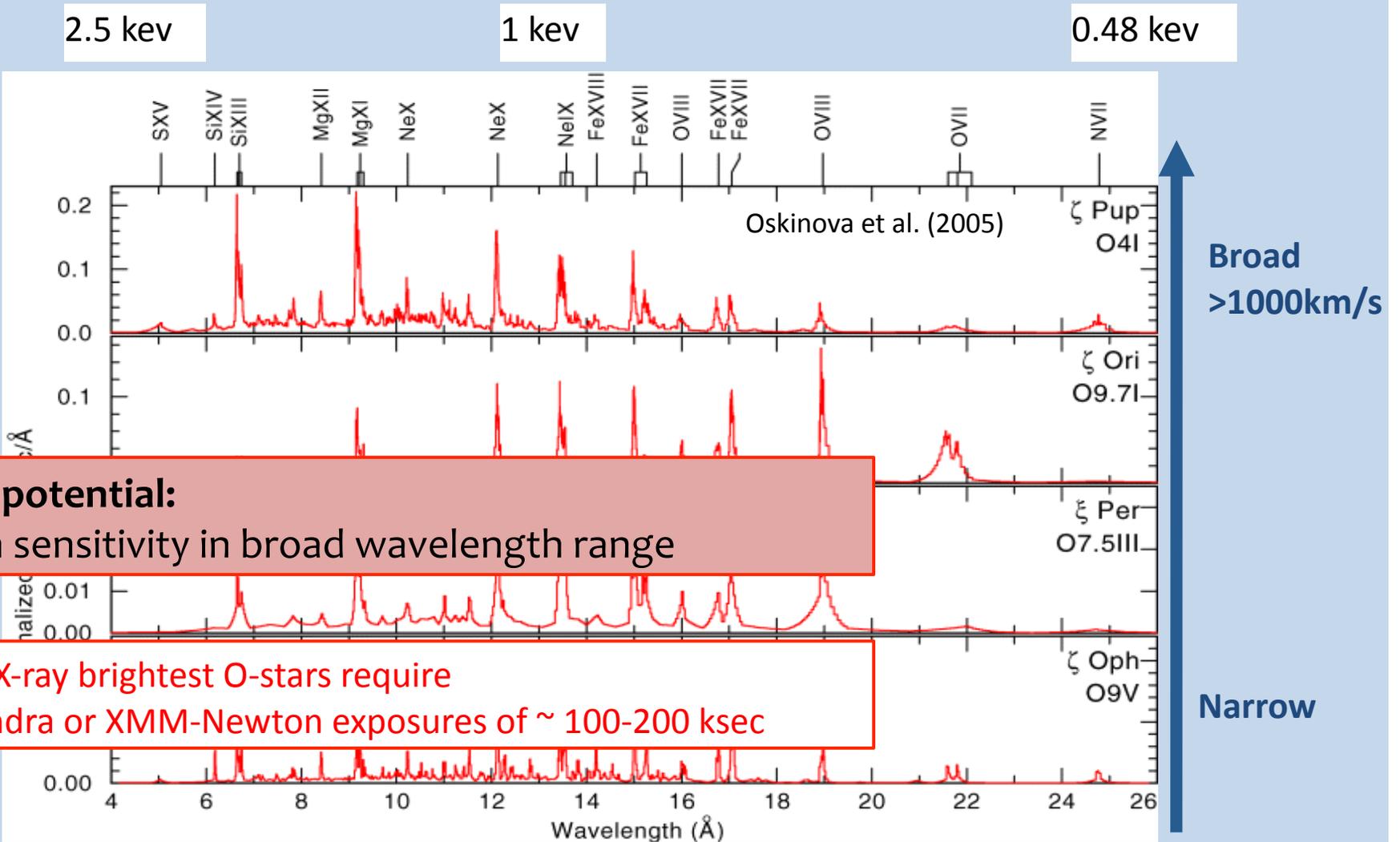
Single O stars:
 $L_x/L_{bol} \sim 10^{-7}$
 $T_x < 1$ keV

Radiative wind shocks

Some O stars with high L_x and high T_x
 \rightarrow Colliding wind binaries ?
 \rightarrow Magnetically confined wind shocks ?

Gagne et al. (2011); from the Chandra Carina Complex Project (CCCP)

High-resolution spectroscopy of hot stars: line broadening (winds)



IXO potential:
high sensitivity in broad wavelength range

The X-ray brightest O-stars require
Chandra or XMM-Newton exposures of ~ 100-200 ksec

IXO/XMS SIMILAR RES. HIGHER SIGNAL

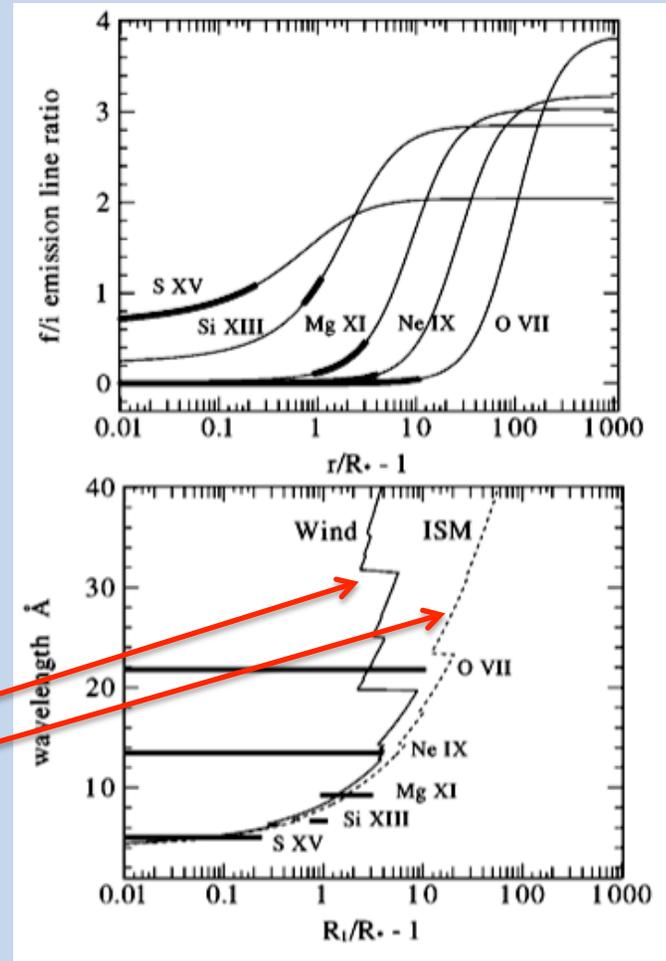
High-resolution spectroscopy of hot stars: Localizing the X-ray source

R = f/i of He-like triplets
is sensitive to UV-pumping
→ yields distance X-ray source / star:

$$\mathcal{R}(r) = \mathcal{R}_0 \frac{1}{1 + 2PW(r)}$$

$$W(r) = \frac{1}{2} \{1 - [1 - (R_*/r)^2]^{1/2}\}$$

$\tau=1$



Observed f/radii consistent with
 $\tau = 1$ radius (Cassinelli & Waldron 2001)

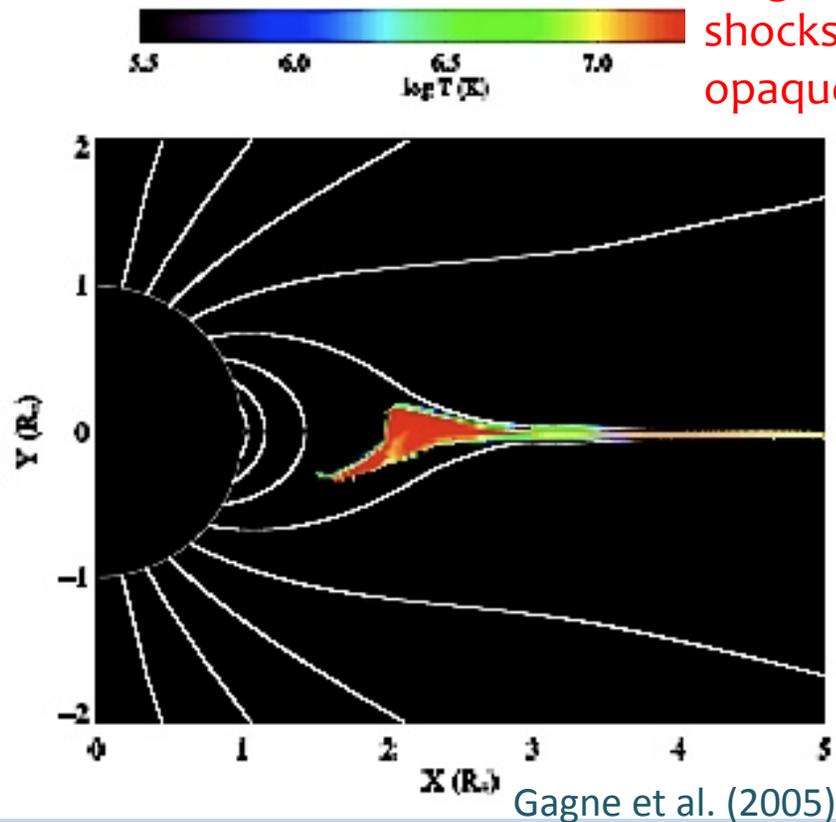
Time-resolved spectroscopy of hot stars: Magnetically confined wind shocks

MCWS scenario:

magn.field channels wind to equator

shocks from collision of winds from 2 hemispheres

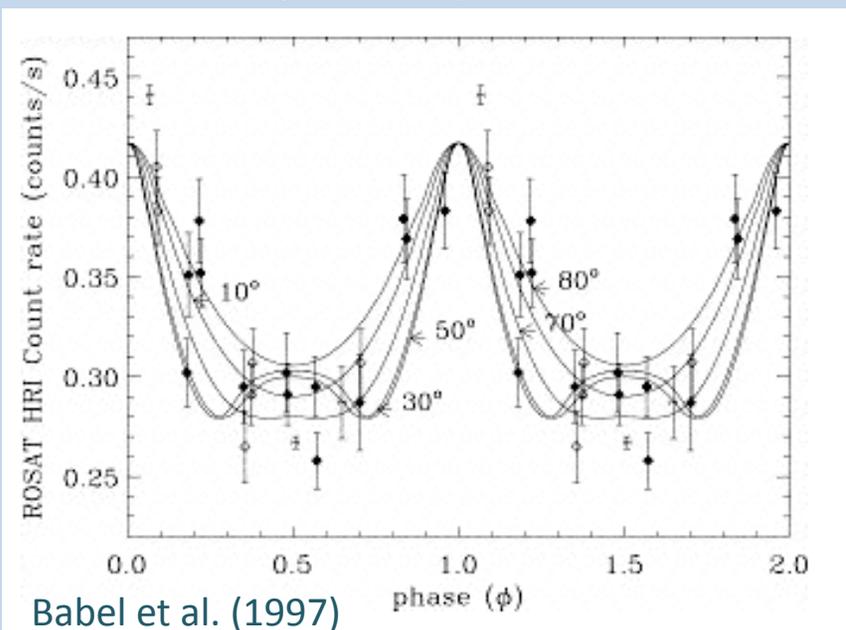
opaque cooling disk modulates X-rays thru rotation cycle



MHD simulations:

- $T \sim 30$ MK
- narrow, sym. line profiles

Θ^1 Ori C (O7V star):



Chandra/HETG: narrow lines, high T_x , $R < 1.7R_*$

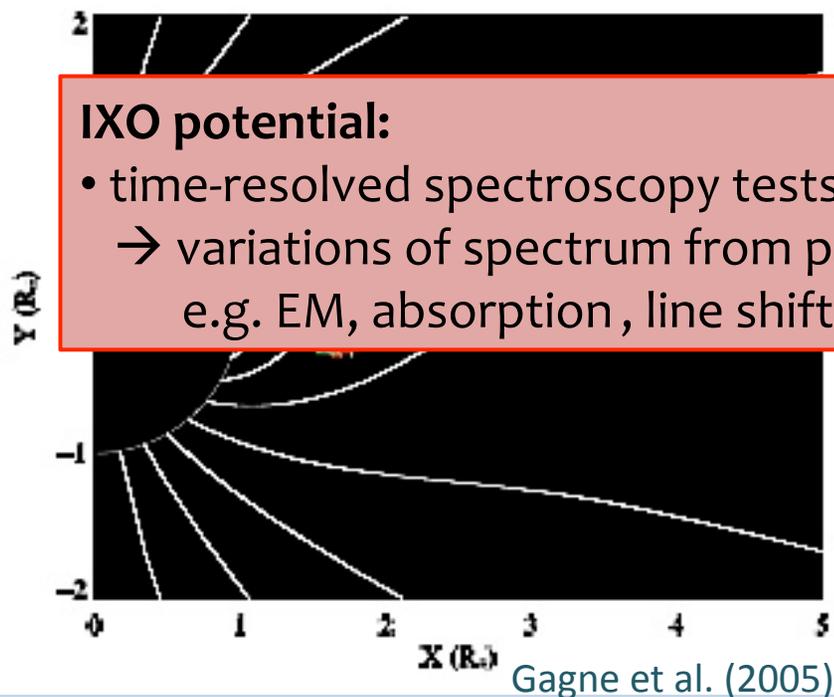
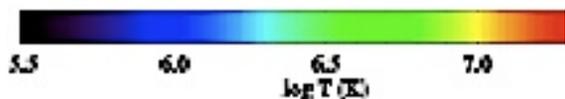
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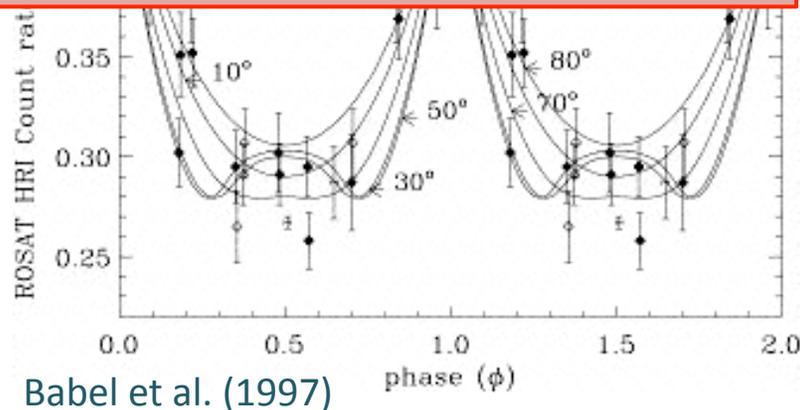


IXO potential:

- time-resolved spectroscopy tests the MCWS model

→ variations of spectrum from partially occulted post-shock region:

e.g. EM, absorption, line shifts + broadening, location of X-ray plasma



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Magnetically confined wind shocks

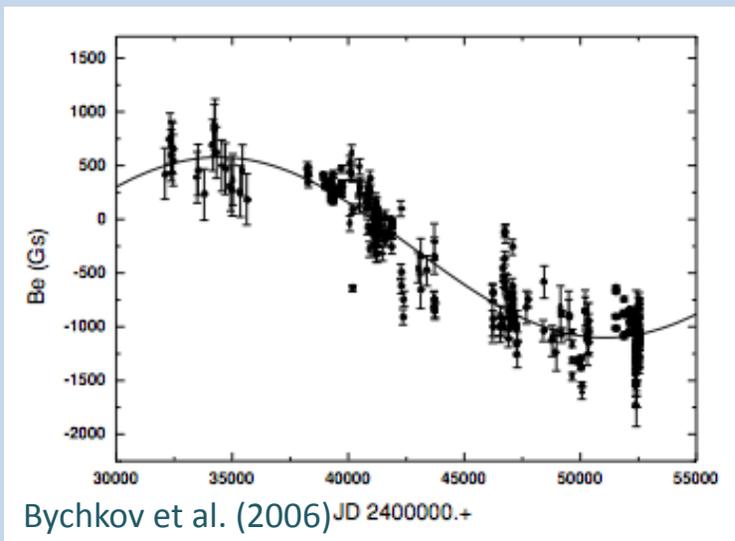
X-rays from A-type stars ??

- no strong winds → no radiative wind shocks
- no convection zone → no corona

But: what about magnetic stars ?

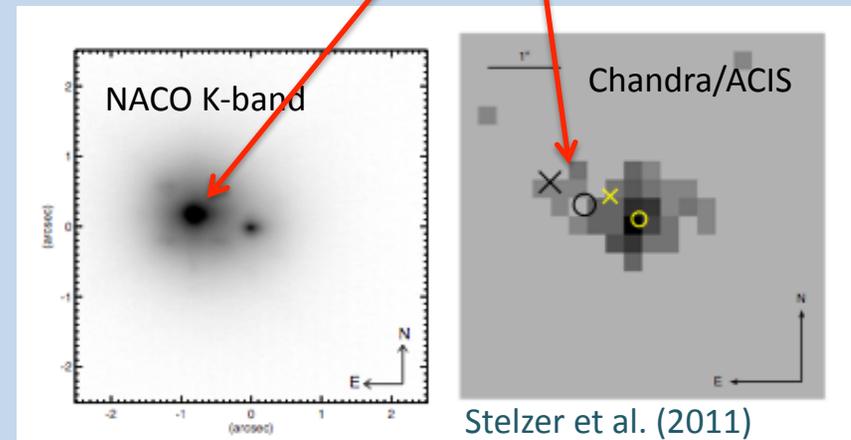
MCWS model devised for Ap star IQ Aur ($\log L_x \sim 29.6$ erg/s) (Babel & Montmerle 1997)

The case of γ Equu:



→ Oblique rotator: modulation of magn.field (P ~ 76yrs !)

IXO potential:
detecting X-ray faint Ap stars



→ Very faint X-ray source

$$L_x \simeq 2.6 \cdot 10^{30} \text{ erg/s} \cdot \left(\frac{B_*}{1 \text{ kG}}\right)^{0.4} \xi$$

and

$$\xi = \left(\frac{\dot{M}_W}{10^{-10} M_\odot/\text{yr}}\right)^\delta \left(\frac{v_\infty}{10^3 \text{ km/s}}\right)^\epsilon$$

$$B \sim 1 \text{ kG}$$

$$\log L_x \sim 26.6 \text{ erg/s}$$

$$v_\infty \sim 600 \text{ km/s}$$

→

$$\text{Mass loss} \sim 10^{-14} M_{\text{sun}}/\text{yr}$$

Wolf-Rayet stars with IXO

Massive stars ($> 25 M_{\text{sun}}$)
with strong winds that strip the H-atmosphere:

WN



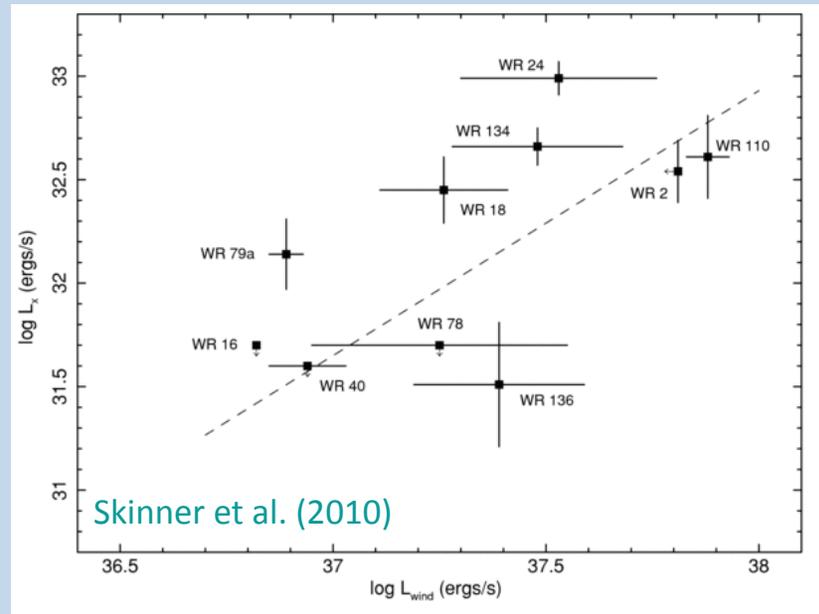
No L_x/L_{bol} relation + high T_x ;
connection with wind parameters

WC

WO



Type I SN



X-ray emission mechanisms:

- radiative winds (like OB stars)
- colliding wind shocks (CWS) in binaries

Wolf-Rayet stars with IXO

Massive stars ($> 25 M_{\text{sun}}$)
with strong winds that strip the H-atmosphere:

WN

WC

WO



Type I SN



Only 1 observed with XMM-Newton:

$L_x = 7 \cdot 10^{30}$ erg/s + hard spectrum (Oskinova et al. 2009)

X-ray emission mechanisms:

- radiative winds (like OB stars)
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Wolf-Rayet stars with IXO

Massive stars ($> 25 M_{\text{sun}}$)
with strong winds that strip the H-atmosphere:

WN

WC



No X-ray detection yet $L_x < 3 \cdot 10^{30}$ erg/s
(due to higher wind opacity?) (Oskinova et al. 2003)

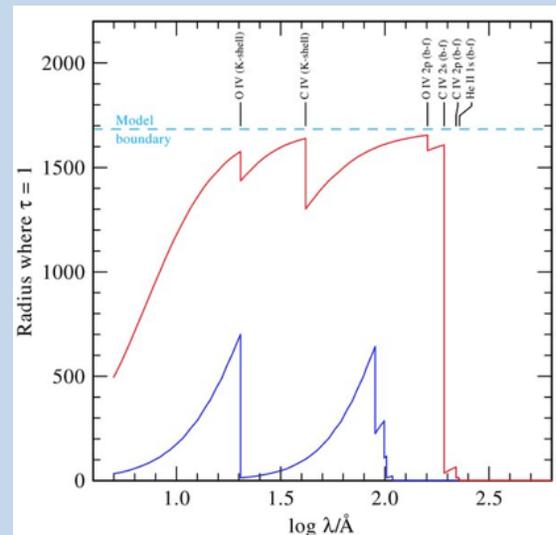
WO



Type I SN

X-ray emission mechanisms:

- radiative winds (like OB stars)
- colliding wind shocks (CWS) in binaries



Oskinova et al. (2009)

Wolf-Rayet stars with IXO

Massive stars ($> 25 M_{\text{sun}}$)
with strong winds that strip the H-atmosphere:

WN

WC

WO



Type I SN

No X-ray detection yet $L_x < 3 \cdot 10^{30}$ erg/s
(due to higher wind opacity?) (Oskinova et al. 2003)

IXO/WFI:

search for faint X-rays from WCs

IXO/XGS+XMS:

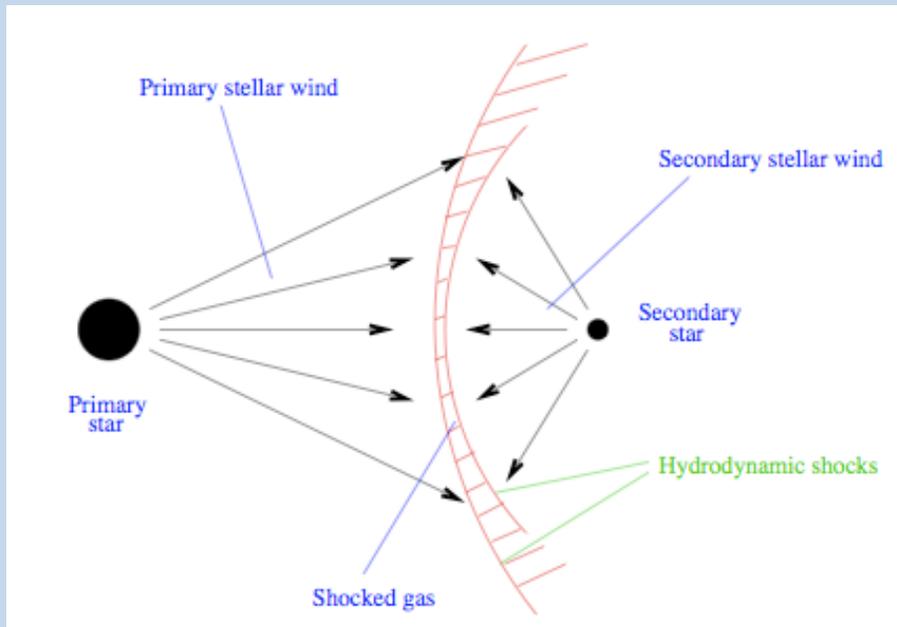
determine emission site using fir-diagnostics

X-ray emission mechanisms:

- radiative winds (like OB stars)
- colliding wind shocks (CWS) in binaries

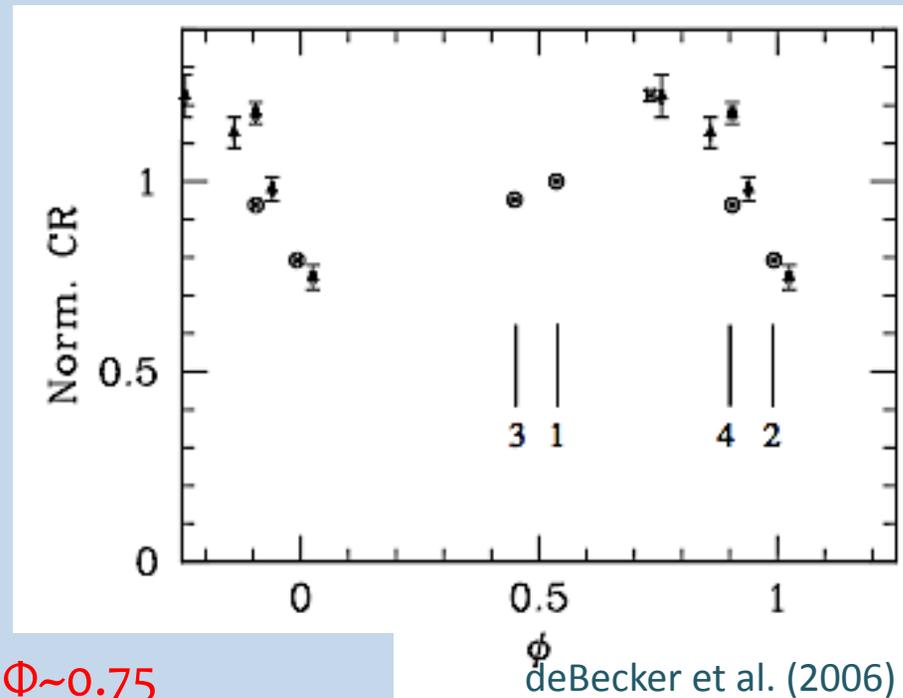
No high-resolution X-ray spectrum
of a single WR star exists !

Time-resolved spectroscopy of hot stars: Colliding wind binaries



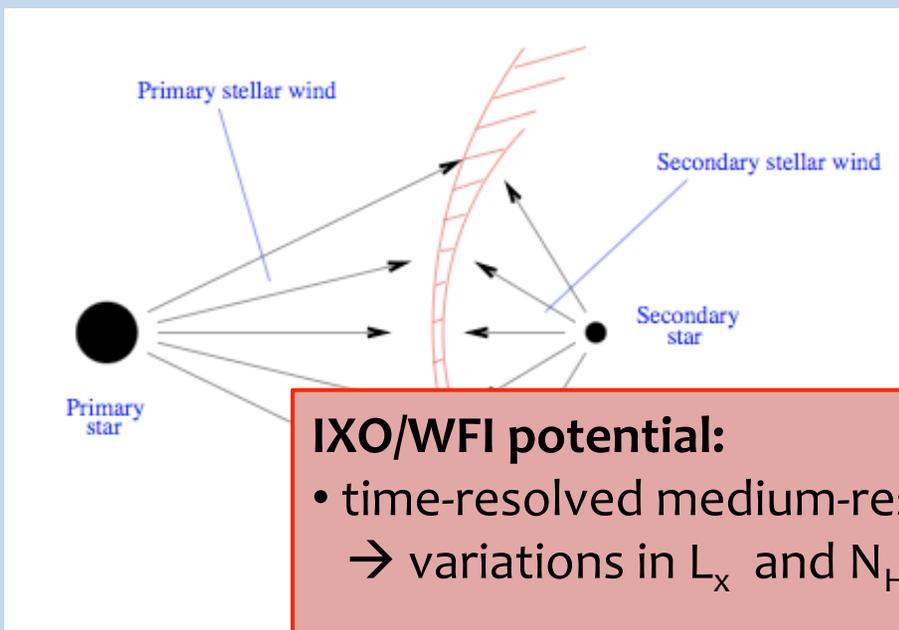
CygOB2 #8a:

- eccentric binary of 2 O-stars (P~22d)
- soft X-rays from colliding winds: $L_x \sim 10^{34}$ erg/s



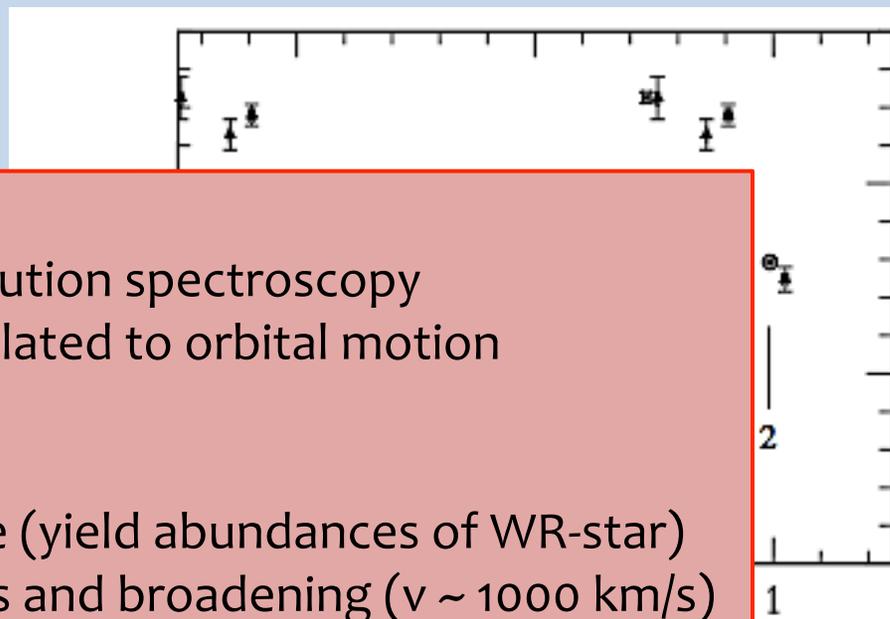
Phase-locked X-ray variability with max. at $\Phi \sim 0.75$
consistent with HD simulations of wind-wind collisions:
(A) Orbital modulation due to changing N_H
(B) Varying shock conditions due to changing separation

Time-resolved spectroscopy of hot stars: Colliding wind binaries



CygOB2 #8a:

- eccentric binary of 2 O-stars (P~22d)
- soft X-rays from colliding winds: $L_x \sim 10^{34}$ erg/s



IXO/WFI potential:

- time-resolved medium-resolution spectroscopy
→ variations in L_x and N_H related to orbital motion

IXO/XGS+XMS potential:

- abundances in collision zone (yield abundances of WR-star)
- wind geometry via line shifts and broadening ($v \sim 1000$ km/s)

Phase-locked X-ray variability with max. at $\Phi \sim 0.75$
consistent with HD simulations of wind-wind collisions:

- (A) Orbital modulation due to changing N_H
- (B) Varying shock conditions due to changing separation

ϕ
deBecker et al. (2006)

High sensitivity for faint X-ray sources

- Brown dwarfs: L_x/L_{bol} in SFR like TTS ? L_R / L_X for field BDs ? (Benz-Guedel)
- Fe $K\alpha$ emission from stellar photospheres
- Wolf-Rayet stars

Spatial resolution
for star forming regions

High-resolution spectroscopy

- density diagnostics: accretion vs. coronal X-rays in T Tauri stars and BDs
- localizing X-ray source in high-mass stars

Time-resolved spectroscopy

- Origin of Fe $K\alpha$ emission: fluorescence? Electron impact ionization?
- Orbital and rotational modulations in colliding wind binaries, magn.confined winds, magn.active regions on cool stars...